CONTRACT SERIAL NO.
06SQ.23440-6-9145-01-SQ

CONTRACTOR: SCULLY MINE

TITLE: TO IMPROVE IRON ORE RECOVERY AT SCULLY MINE - PHASE IV (Canada/Newfoundland Mineral Development Agreement)

Final Report
by:

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Work on the project was conducted under the auspices of the Canada Centre for Energy Technology, Energy, Mines and Resources Canada.

DSS File No. 06SQ.23440-6-9145

DSS Contract Serial No. 23440-7-9154/01-SQ

CANMET SCIENTIFIC AUTHORITY: Dr. M. Stefanski

Date: June 5, 1991

MICROMEDIA
42 pp

BACKGROUND

PHASE IV is the final phase of the MDA and involves optimization of the prototype mill circuit. More specifically, the objective is to characterize the ore at Scully Mine with regard to power draw, recirculating load, spiral feed density, etc. so that the milling conditions can be optimized to improve spiral recovery. This will be achieved through improved process control along with the development of an expert control system for the grinding and spiral circuits.

From March 5-16, 1990 personnel from Comdale Technologies were on-site at the Scully Mine to commission the start-up of the grind control system for #4 mill. Since March 16th the system has been kept on-line so that monitoring and testing of the mill performance can begin. Evaluation of the circuit has been on-going.

This report will provide some insight into the grind control system and will present performance results of this system which is on-line on Mill #4. This report is the final report of the PHASE IV project.

THE COMDALE/C EXPERT SYSTEM

The Comdale/C process control system is an expert system development tool which can be used to create real-time expert systems for process control. Expert systems, a sub-field of Artificial Intelligence, are computer programs which allow you to encode the expertise of a human expert in a form that will enable the computer to solve problems that the expert would normally solve. This expertise is stored in the Comdale/C knowledge base which was created by Comdale personnel in collaboration with Wabush Mines operating personnel. The expertise is broken down into segments, and each segment is represented in the form of if-then production rules. All rules have a simple English-like syntax, and can accomodate multiple conditions and conclusions. The knowledge base created for Wabush Mines is included in ATTACHMENT I and to-date contains around 80 rules.

The Comdale/C process control system runs under the QNX operating system on a Compaq Deskpro 386 microcomputer. The knowledge base runs simultaneously along with other tasks which include communications with external hardware, making intelligent decisions, scheduling the occurence of different events, database management and responding to requests made by the operator.

The grind control system communicates with eleven Foxboro single-loop controllers which are directly connected to the final control instrumentation. The instrumentation which was upgraded and retrofitted on Mill #4 as part of this project is depicted on the flowsheet diagram presented in FIGURE 1. On the autogenous mill there is power draw measurement and ore tonnage and water addition control. On the recirculating and spiral feed pumps are level, flowrate and density sensors. On the rougher and cleaner spirals and the rougher concentrate stream there is water addition control.

The knowledge base has been designed to achieve the following:

1) Attempt to maintain spiral feed densities at the desired level of 25-30% solids. The density is controlled by water addition rates to the mill feed chute and spiral and recirculating pumpboxes.

2) Control mill power draw. The system will adjust mill feed tonnage rates based on mill power draw.

3) Control spiral concentrate grade by automatically adjusting spiral washwater flowrates.

RESULTS AND DISCUSSION

Since its startup on March 16,1990 the grind control system has worked extremely well. The system has provided the following benefits:

A) Increased fine iron recovery due to improved spiral density control.
B) Improved mill throughput when processing hard ore
C) Improved spiral washwater control

Each of the above will be described in more detail below:

A) Improved Spiral Density Control

The primary goal of the Expert System is to try and maintain a constant spiral feed density under varying feed conditions. Maintaining a high feed density (approx. 30% solids by weight) is a critical factor for ensuring maximum spiral efficiency and performance, particularly for recovery of fine iron.

The Expert System reads the spiral density from the density meters on the spiral feed lines. If this density is not optimum, it then checks several other critical variables and "decides" if the rate of water addition can be adjusted to improve the existing spiral density. If so, these addition rates are automatically adjusted. The water addition control points consist of spiral and recirculating pumpbox makeup water and mill feedchute water. It should be noted that the standard method of controling water addition to the mill was to manually set the water addition controls at their midpoint values. Normally, these would only rarely be adjusted despite changes in mill ore type, milling rate , etc.

FIGURE 2 presents a graph of spiral pumpbox level and spiral feed density against time. The spiral feed density remains relatively constant while the pumpbox level varies considerably over the indicated time period. The Expert System increased the water addition to the pumpbox (causing the level to rise) in order to maintain the desired spiral feed density.

In this manner the Expert System on Mill #4 has been able to maintain a higher and more desirable feed density, particularly under varying feed tonnages on the mill. FIGURE 3 shows how the spiral feed density versus mill tonnage curve has been improved under the influence of constant water addition control. Since commissioning the Expert System, the spiral feed density on Mill #4 has averaged approximately 28% solids compared to only about 25% solids on the other mill lines. Although there are other differences between Mill #4 and the other mill lines, it is believed that this higher density has accounted for an improvement in spiral circuit weight recovery of an estimated 1.50 percentage points.

B) Improved Mill Throughput When Processing Hard Ore

A very significant benefit offered by the Expert System is more precise control over the mill power draw. The system will cut back on mill feedrate if the power reaches the critical level of 60 % but will immediately try and reestablish the tonnage to the desired level. Under the old mill control system these increases and decreases had to be done manually. Often times the operator would not notice if power values had returned to normal levels and as a result the mill feedrate would remain below desired levels for excessive periods of time.

The Expert System has been configured to make the smallest possible incremental changes to the mill tonnage rate to maintain maximum throughput while avoiding the risk of overloading the mill (excessive power draw). Test results have indicated that during periods of hard feed ores, the Expert System circuit has averaged 387 LTPH while the standard mill circuits only 356 LTPH (FIGURE 4).

FIGURE 5 illustrates, in a simplified manner, how this improvement is achieved. When mill power draw is near the desirable upper limit the Expert sytem will constantly adjust the mill tonnage, cutting back when the power draw reaches maximun and increasing when the power draw falls below this upper limit. The standard circuit involves a manual adjustment by the control room operator. When the power draw reaches maximum the tonnage is cut, normally by 20-50 LTPH. The manpower is not available to constantly monitor the mill power and make fine tonnage adjustments and therefore the tonnage rate cannot be optimized.

ATTACHMENT II is a copy of an actual tonnage recording chart from Mill #4 under the Expert System control. This chart shows how the tonnage is decreased and later increased as the mill power varies.

C) Improved Spiral Concentrate Grade Control

Washwater addition on the spiral circuit is used to control spiral concentrate silica levels. Water is introduced to the spiral circuit in three locations: rougher spiral washwater, cleaner spiral washwater, and rougher concentrate dilution water. These points of water addition are the most important means of affecting the silica grade of the cleaner spiral concentrate produced from the spiral circuit. Increasing the washwater level improves the grade by forcing more silica to tailings. Lowering the water level allows more silica to enter the concnetrate ports and results in a lower grade of final concentrate.

The silica grades of the cleaner spiral concentrate are entered into the Expert System by the control room operator every hour. (Eventually this information will be automatically entered into the system from a computer network system link with the laboratory). The Expert System will read these concentratre grades and automaticallly adjust the washwater flowrates to attempt to bring the grade within the desired specification. Normally the washwater would have to be adjusted manually by the spiral attendant, after being requested to do so by the control room operator. This manual method suffers from slow response time. With the Expert System an improvement in grade control capability has been achieved.

CONCLUSIONS

The Expert System for mill grind control at the Scully Mine has proven itself to be a valuable asset in the operation of Mill #4. This system has provided benefits of improved spiral weight recovery, increased mill throughput while processing hard ore and improved silica grade control in the spiral concentrate.

The control room operators have readily accepted this system. It has provided them with more information and enabled them to make changes, when required, on the milling circuit more quickly and efficiently than was previously possible. They have found the system to be reliable and easy to operate.

With the never ending requirement for increased productivity in the highly competitive field of iron ore mining this grind control Expert System can be easily justified. Expansion of this system to all six mill lines, at the Wabush Mine, will be the next step in this improvement program.

LIST OF ATTACHMENTS

Attachment I — Copy of the Knowledge Base for Control of the Mill Circuit at Scully Mine as of June 5, 1991.

Attachment II — Recording Chart Showing Control of Mill Tonnage Based on Mill Power Draw

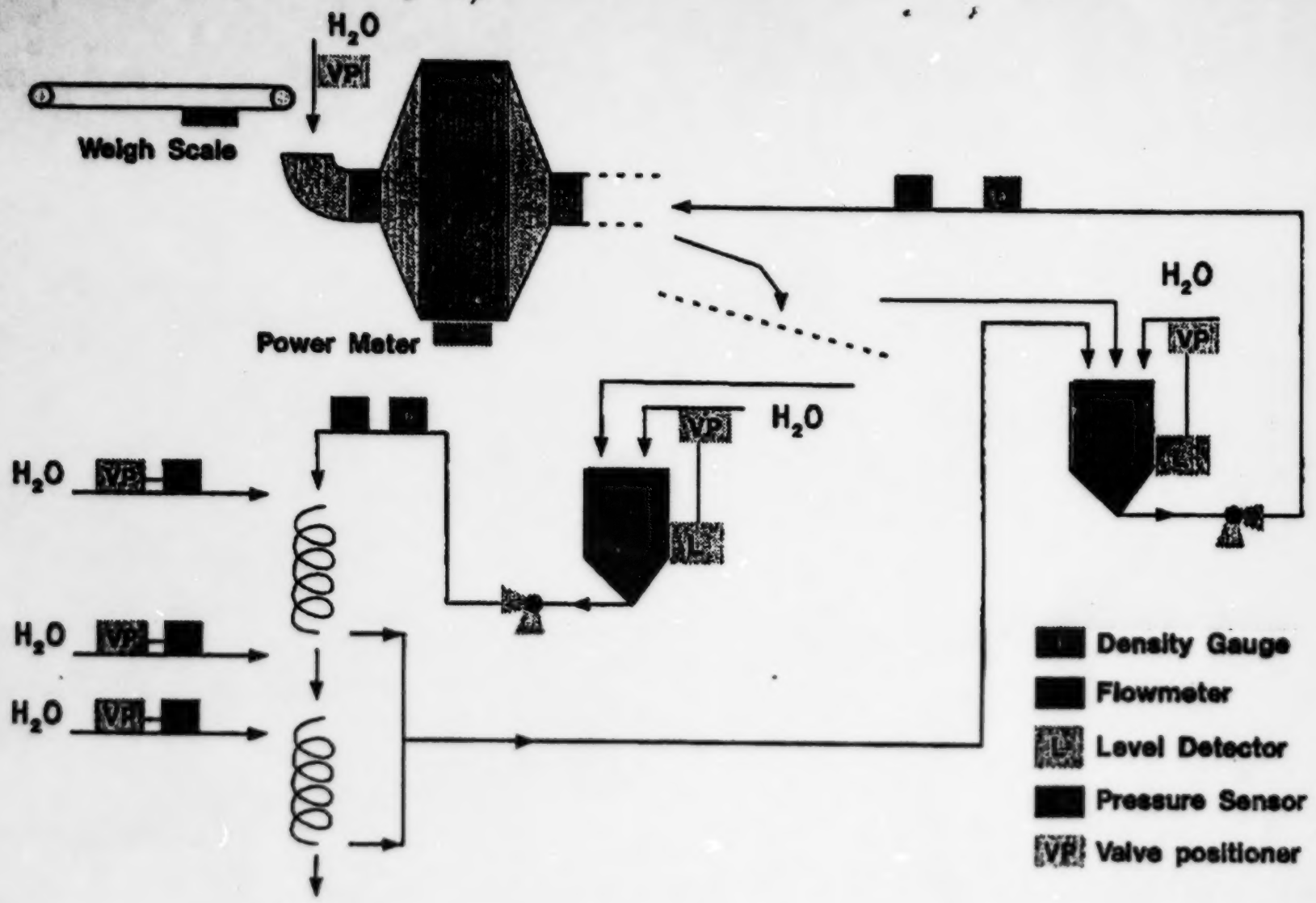

FIGURE 1 Simplified flowsheet showing the location of process control instrumentation

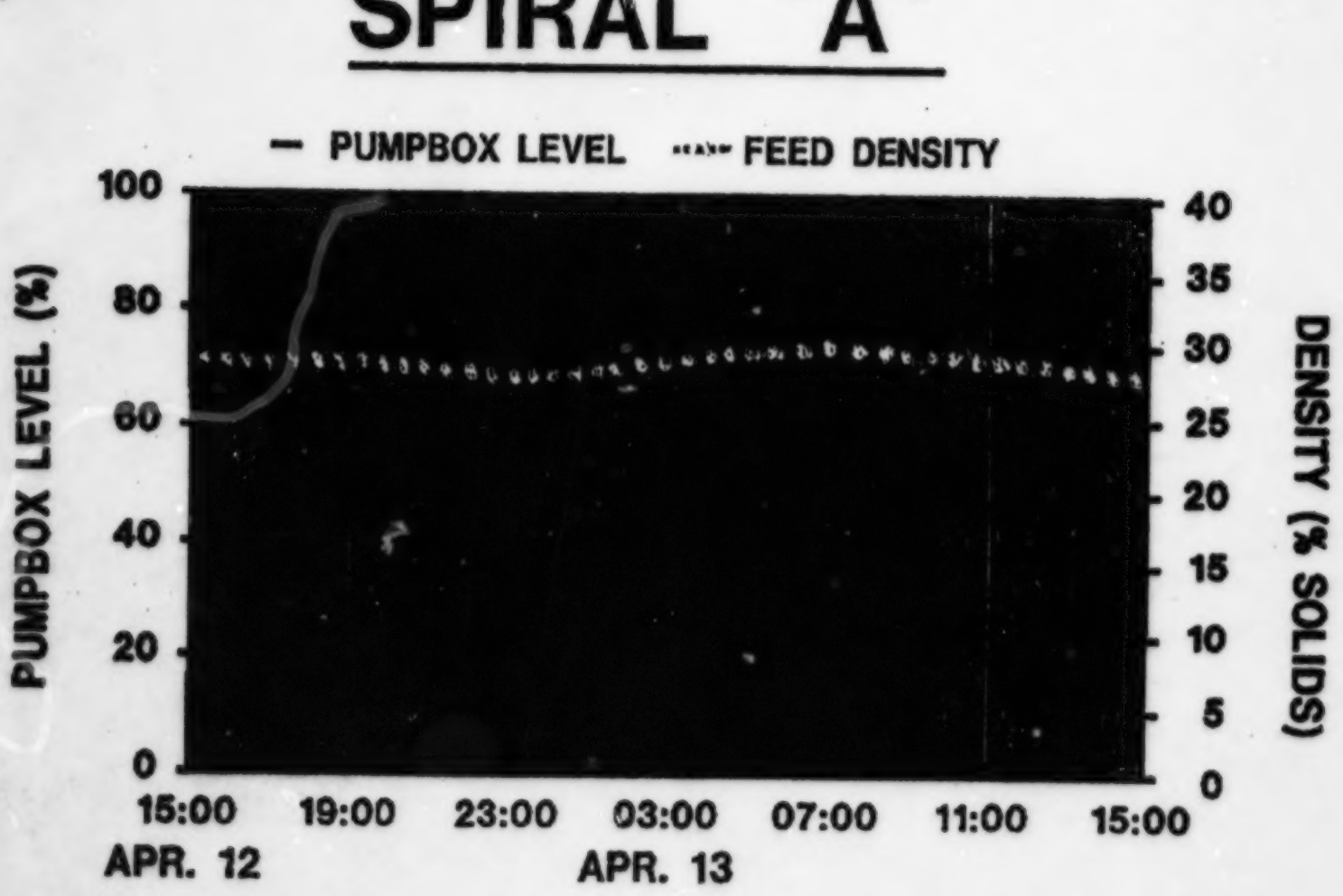

FIGURE 2 Typical spiral density and spiral pumpbox level as a function of time

GRIND CONTROL EFFECT
ON SPIRAL FEED DENSITY

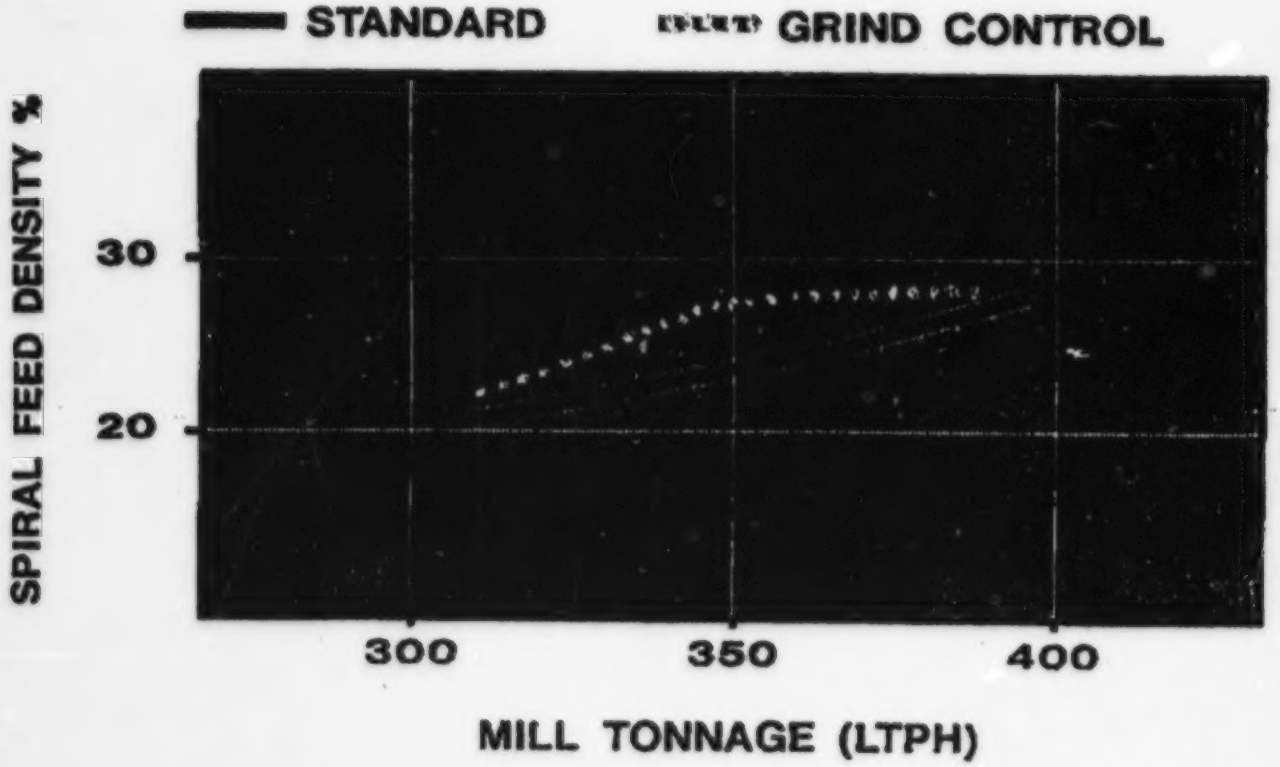

FIGURE 3 Grind control effect on improving spiral feed density

HARD ORE MILL THROUGHPUT

	LTPH
STANDARD CIRCUIT	356
EXPERT SYSTEM	387

FIGURE 4 Mill throughput tonnage while processing hard ore

MILL TROUGHPUT WHEN PROCESSING "HARD" ORE

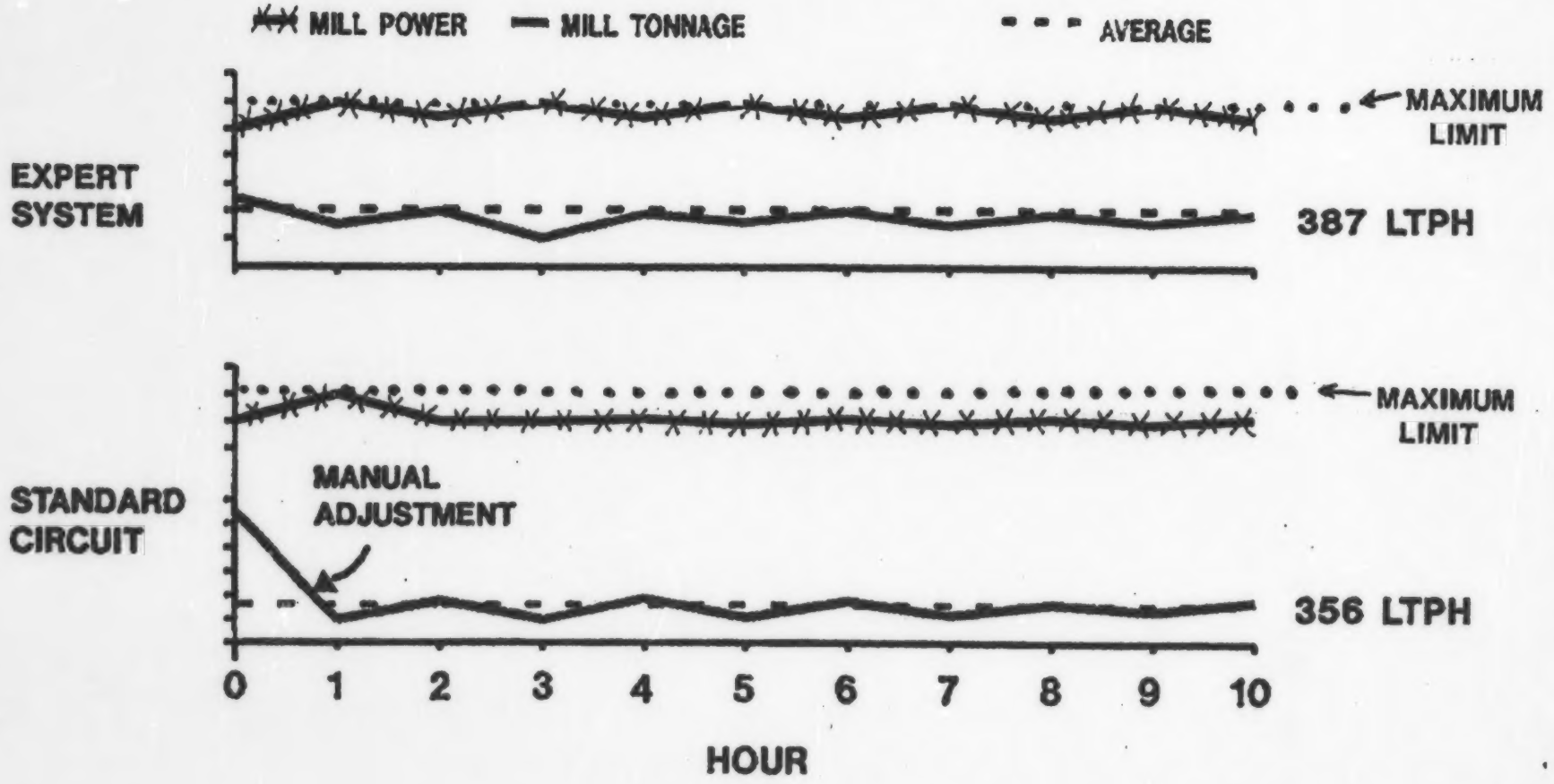

FIGURE 5 Mill tonnage and power draw relationship while processing hard ore

Appendix I to the

Final Report of Phase IV

TITLE: TO IMPROVE IRON ORE RECOVERY AT SCULLY MINE - PHASE IV (Canada/Newfoundland Mineral Development Agreement)

Preliminary Report
by:

Peter Cleyle
Plant Metallurgist
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Work on the project was conducted under the auspices of the Canada Centre for Energy Technology, Energy, Mines and Resources Canada.

DSS File No. 06SQ.23440-6-9145

DSS Contract Serial No. 23440-6-9145/01-SQ

CANMET SCIENTIFIC AUTHORITY: Dr.M.Stefanski

Date: March 20,1990

BACKGROUND

PHASE IV is the final phase of the MDA and involves optimization of the prototype mill circuit. More specifically, the objective is to characterize the ore at Scully Mine with regard to power draw, recirculating load, spiral feed density, etc. so that the milling conditions can be optimized to improve spiral recovery. This will be achieved through improved process control along with the development of an expert control system for the grinding and spiral circuits.

From March 5-16, 1990 personnel from Comdale Technologies were on-site at the Scully Mine to commission the start-up of the grind control system for #4 mill. Since March 16th the system has been kept on-line so that monitoring and testing of the mill circuit performance can begin. Proper evaluation of the circuit is estimated to take approximately two months.

This report will provide some insight into the grind control system and how it works. This report is a preliminary report only and will be followed by a final report on PHASE IV when the system has been fully evaluated.

THE COMDALE/C EXPERT SYSTEM

The Comdale/C process control system is an expert system development tool which can be used to create real-time expert systems for process control. Expert systems, a sub-field of Artificial Intelligence, are computer programs which allow you to encode the expertise of a human expert in a form that will enable the computer to solve problems that the expert would normally solve. This expertise is stored in the Comdale/C knowledge base which was created by Comdale personnel in collaboration with Wabush Mines operating personnel. The expertise is broken down into segments, and each segment is represented in the form of if-then production rules. All rules have a simple English-like syntax, and can accomodate multiple conditions and conclusions. The knowledge base created for Wabush Mines is included in ATTACHMENT I and to-date contains sixty-six rules.

The Comdale/C process control system runs under the QNX operating system on a Compaq Deskpro 386 microcomputer. The knowledge base runs simultaneously along with other tasks which include communications with external hardware, making intelligent decisions, scheduling the occurence of different events, database management and responding to requests made by the operator.

The knowledge base has been designed to achieve the following:

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2) Control mill power draw. The system will adjust mill feed tonnage rates based on mill power draw.

3) Control spiral concentrate grade by automatically adjusting spiral washwater flowrates.

RESULTS AND DISCUSSION

Since its startup on March 16,1990 the grind control system has worked extremely well. The biggest benefit realized to-date is the control over the mill power draw. The system will cut back on mill feedrate if the power reaches the critical level of 60 % and after the power stabilizes the tonnage will be reincreased (ATTACHMENT II). Under the old mill control system these increases and decreases had to be done manually. Often times the operator would not notice if power values had returned to normal levels and as a result the mill feedrate will remain below desired levels for excessive periods of time.

Determining the effect of the grind control system on spiral circuit performance and recovery will require a longer period of evaluation. Through a sampling program the performance of the spirals on mill #4 are being compared to those on an adjacent mill line with regard to product grade and recovery.

LIST OF ATTACHMENTS

Attachment I — Copy of the Knowledge Base for Control of the Mill Circuit at Scully Mine as of March 16,1990.

Attachment II — Recording Chart Showing Control of Mill Tonnage Based on Mill Power Draw

TITLE

AUTOGENOUS MILL CONTROL

COMDALE/C
THE AUTOGENOUS MILL CONTROLLER

WABUSH MINES LIMITED

SCULLY MINE
LABRADOR
CANADA

FOR CONTROL OF AN AUTOGENOUS MILL/SPIRAL CIRCUIT

```
!* default user name *!
NAME Operator

!* set confidence level *!
CONFIDENCE 50

!* no explanation of text messages *!
TEXTWHY OFF

!********  THE FIRST RULE ACTS AS A CONTROLLING RULE FOR SEARCHING   ********!
!*****************            THE  KNOWLEDGE  BASE                 **********************!


rule 1
     if $ system_statement is true
     then FIND ore type known;
     then FIND spirals metallurgical_performance ok ;                    cf = 100
     then FIND spirals operating_condition ok ;                          cf = 100
     then FIND mill operating_condition ok ;                             cf = 100
     then MACRO 2;                                                       cf = 100
     then process state is checked_and_problems_found_corrected          cf = 100 #

!************************ CONGRATS TO THE OPERATOR ************************!
!* then check if we can increase tonnage *!



rule 2
     if   spirals metallurgical_performance is ok
     and  spirals operating_condition is ok
     and  mill operating_condition is ok
     then TEXT
     ==========================================================
          The plant seems to be operating fine right now.
          Keep up the good work and be on the lookout for
          potential problems.
     ==========================================================#          cf = 100
     then WAIT 600 ;
```

```
        if   spirals metallurgical_performance is ok
        and  spirals operating_condition is ok
        and  mill operating_condition is ok
        and  circuit weight_recovery is_more_or_less ok
        and  mill feedwater_valve_position /
             maximum mill_feedwater_valve_position
        and  mill feed_rate_setpoint /
             maximum mill_feed_rate_setpoint
        and  recirculating_load density is_definitely_not too_high
        then mill feed_rate_setpoint is increased_a_little_bit          cf = 100

        then CHANGE mill feed_rate_setpoint increased_a_little_bit ;    cf = 100

        then WAIT 1200 ;
        then TEXT                                                       cf = 100
        ==========================================================
             The plant seems to be operating fine right now.
             Keep up the good work and be on the lookout for
             potential problems.

         Your mill feedrate was just increased by a little bit.
        ==========================================================#     cf = 100#


!*** NOTE: The statements below have been taken out of the Rules because ****!
!***       previously we automatically increase feedwater whenever the   ****!
!***       feedrate is increased. Presently this is not done.            ****!

!***then mill feedwater_valve_position is increased_a_little_bit cf = 100****!
!***then CHANGE mill feedwater_valve_position increased_a_little_bit;cf=100**!


!****** CHARACTERIZE THE ORE TYPE AND SET OPERATING PARAMETERS **************!

!* Characterize ore as low_power, normal or high_power and IMPORT   *!
!* maximum and minimum values for set points                        *!
!* if any one of these rules is successful then we wait for half hour
   before checking ore type again *!


RULE 4
        if mill power_draw is low_power_ore
        and mill power_draw  is steady_low_power
        then ore type is low_power_ore
        then IMPORT low_pow.dat CIF;                    cf = 100
        then TEXT                                       cf = 100
        ==========================================================
             We are now milling low-power ore.
        ==========================================================#    cf = 100
        then APPLYRULE ore type low_power_ore ;         cf = 100
        then ore type is known                          cf = 100
        then WAIT 1800 ;                                cf = 100 #
```

```
RULE 5
      if  mill power_draw is normal_power_ore
      and mill power_draw is steady_normal_power
      then ore type is normal_power_ore                    cf = 100
      then IMPORT normal.dat CIF;                          cf = 100
      then TEXT
      ==========================================================
           We are now milling normal-power ore.
      ==========================================================#    cf = 100
      then APPLYRULE ore type normal_power_ore ;           cf = 100
      then ore type is known                               cf = 100
      then WAIT 1800 ;                                     cf = 100 #


RULE 6
      if mill power_draw is high_power_ore
      and mill power_draw is steady_high_power
      then ore type is high_power_ore                      cf = 100
      then IMPORT high_pow.dat CIF;                        cf = 100
      then TEXT
      ==========================================================
           We are now milling high-power ore.
      ==========================================================#    cf = 100
      then APPLYRULE ore type high_power_ore ;             cf = 100
      then ore type is known                               cf = 100
      then WAIT 1800 ;                                     cf = 100 #


!*******     TEST SPIRALS METALLURGICAL PERFORMANCE          **********!


RULE 7
      if spiral_A feed_density is too_high
      or spiral_B feed_density is too_high
      or spiral_A feed_density is too_low
      or spiral_B feed_density is too_low
      or circuit silica_content is too_low
      or circuit silica_content is too_high
      or circuit weight_recovery is too_high
      or circuit weight_recovery is too_low

      then FIND * metallurgical_problem  * ;  cf = 100
      then spirals metallurgical_performance is_not ok    cf = 100 #


!******************   TEST FOR OPERATING CONDITIONS      **********************!
!********                 IN THE SPIRALS CIRCUIT                    **********.


RULE 8
      if spiral_A sump_level is too_high
      or spiral_B sump_level is too_high
      or spiral_A sump_level is too_low
      or spiral_B sump_level is too_low

      then FIND * spiral_operating_problem  * ;     cf = 100
      then spirals operating_condition is_not ok    cf = 100 #
```

```
!************************ TEST MILL OPERATION ***************************!

RULE 9
      if mill power_draw is too_high
      or mill power_draw is high_power_ore
      and mill power_draw is trending_upward_fast
      or mill power_draw is too_low
      or mill power_draw is low_power_ore
      and mill power_draw is trending_downward_fast
      or recirculating_sump level is too_high
      or recirculating_sump level is too_low
      or recirculating_load density is too_high
      or recirculating_load density is too_low
      or recirculating_load flowrate is too_low
      or mill condition is backspilling
      or mill feedwater_flowrate is too_low

      then mill operating_condition is_not ok                    cf = 100
      then FIND mill operating_problem *     ;                   cf = 100  #


!************   SPIRALS METALLURGICAL PERFORMANCE   ********************!

!* spiral feed densities too high *!
!* Rules 10 and 11 adjust spiral A and B sump level setpoint separately *!


RULE 10
      if spiral_A feed_density is too_high
      and spiral_A feed_density is trending_upward
      and spiral_A feed_sump_level_setpoint <
          maximum spiral_circuit_feed_sump_level_setpoint
      then spiral_A metallurgical_problem is density_too_high    cf = 100
      then spiral_A feed_sump_level_setpoint is increased_a_lot  cf = 100

then CHANGE spiral_A feed_sump_level_setpoint increased_a_lot ; cf = 100

then WAIT ALLCONCL spiral_A metallurgical_problem density_too_high 600 ;cf = 100


RULE 11
      if spiral_B feed_density is too_high
      and spiral_B feed_density is trending_upward
      and spiral_B feed_sump_level_setpoint <
          maximum spiral_circuit_feed_sump_level_setpoint
      then spiral_B metallurgical_problem is density_too_high    cf = 100
      then spiral_B feed_sump_level_setpoint is increased_a_lot  cf = 100

then CHANGE spiral_B feed_sump_level_setpoint increased_a_lot ; cf = 100

then WAIT ALLCONCL spiral_B metallurgical_problem density_too_high 600 ;cf = 100
```

```
RULE 12
      if spiral_A feed_density is too_high
      and spiral_A feed_density is trending_upward
      and spiral_A feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint <
           maximum recirculating_sump_level_setpoint

      or spiral_B feed_density is too_high
      and spiral_B feed_density is trending_upward
      and spiral_B feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint <
           maximum recirculating_sump_level_setpoint

      then spiral_circuit metallurgical_problem is density_too_high    cf = 1
      then recirculating_sump level_setpoint is increased_a_lot        cf = 1

  then CHANGE recirculating_sump level_setpoint increased_a_lot ;      cf = 10

  then WAIT ALLCONCL spiral_circuit metallurgical_problem density_too_high 900


RULE 13
      if spiral_A feed_density is too_high
      and spiral_A feed_density is trending_upward
      and spiral_A feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >=
           maximum recirculating_sump_level_setpoint
      and  mill feedwater_valve_position <
           maximum mill_feedwater_valve_position

      or spiral_B feed_density is too_high
      and spiral_B feed_density is trending_upward
      and spiral_B feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >=
           maximum recirculating_sump_level_setpoint
      and  mill feedwater_valve_position <
           maximum mill_feedwater_valve_position

      then spiral_circuit metallurgical_problem is density_too_high    cf = 1
      then mill feedwater_valve_position is increased_a_lot            cf = 1

  then CHANGE mill feedwater_valve_position increased_a_lot ;          cf = 1

  then WAIT ALLCONCL spiral_circuit metallurgical_problem density_too_high 90

/* here we cut back on mill feedrate as a last resort to help with high
   spiral feed density */
```

```
RULE 14
      if spiral_A feed_density is too_high
      and spiral_A feed_density is trending_upward
      and spiral_A feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >=
           maximum recirculating_sump_level_setpoint
      and  mill feedwater_valve_position >=
           maximum mill_feedwater_valve_position
      and  mill feed_rate_setpoint >
           minimum mill_feed_rate_setpoint

      or spiral_B feed_density is too_high
      and spiral_B feed_density is trending_upward
      and spiral_B feed_sump_level_setpoint >=
           maximum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >=
           maximum recirculating_sump_level_setpoint
      and  mill feedwater_valve_position >=
           maximum mill_feedwater_valve_position
      and  mill feed_rate_setpoint >
           minimum mill_feed_rate_setpoint

      then spiral_circuit metallurgical_problem is density_too_high    cf = 100
      then mill feed_rate_setpoint is decreased_a_little_bit           cf = 100

      then CHANGE mill feed_rate_setpoint decreased_a_little_bit  ;    cf = 100

      then TEXT
      ==========================================================
           The spiral circuit feed density is too high.
           The feed rate has just been decreased.
      ==========================================================$    cf = 100
  then WAIT ALLCONCL spiral_circuit metallurgical_problem density_too_high 900


!* spiral feed densities too low *!
!* Rules 15 and 16 adjust spiral A and B sump level setpoint separately *!


RULE 15
      if spiral_A feed_density is too_low
      and spiral_A feed_density is trending_downward
      and spiral_A feed_sump_level_setpoint >
           minimum spiral_circuit_feed_sump_level_setpoint
      then spiral_A metallurgical_problem is density_too_low     cf = 100
      then spiral_A feed_sump_level_setpoint is decreased_a_lot  cf = 100

then CHANGE spiral_A feed_sump_level_setpoint decreased_a_lot ; cf = 100

then WAIT ALLCONCL spiral_A metallurgical_problem density_too_low 600 ; cf = 1
```

```
RULE 16
      if spiral_B feed_density is too_low
      and spiral_B feed_density is trending_downward
      and spiral_B feed_sump_level_setpoint >
           minimum spiral_circuit_feed_sump_level_setpoint
      then spiral_B metallurgical_problem is density_too_low      cf = 100
      then spiral_B feed_sump_level_setpoint is decreased_a_lot   cf = 100

then CHANGE spiral_B feed_sump_level_setpoint decreased_a_lot ; cf = 100

then WAIT ALLCONCL spiral_B metallurgical_problem density_too_low 600 ; cf = 1


!* do not cut back on water to recirc sump if mill density is high *!


RULE 17
      if spiral_A feed_density is too_low
      and spiral_A feed_density is trending_downward
      and spiral_A feed_sump_level_setpoint <=
           minimum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >
           minimum recirculating_sump_level_setpoint
      and  recirculating_load density is_not too_high

      or spiral_B feed_density is too_low
      and spiral_B feed_density is trending_downward
      and spiral_B feed_sump_level_setpoint <=
           minimum spiral_circuit_feed_sump_level_setpoint
      and  recirculating_sump level_setpoint >
           minimum recirculating_sump_level_setpoint
      and  recirculating_load density is_not too_high

      then spiral_circuit metallurgical_problem is density_too_low      cf = 100
      then recirculating_sump level_setpoint is decreased_a_lot         cf = 100

      then CHANGE recirculating_sump level_setpoint decreased_a_lot ;   cf = 100

    then WAIT ALLCONCL spiral_circuit metallurgical_problem density_too_low 900
```

```
RULE 18
        if spiral_A feed_density is too_low
        and spiral_A feed_density is trending_downward
        and spiral_A feed_sump_level_setpoint <=
             minimum spiral_circuit_feed_sump_level_setpoint
        and  recirculating_sump level_setpoint <=
             minimum recirculating_sump_level_setpoint
        and mill feedwater_valve_position >
            minimum mill_feedwater_valve_position

        or spiral_B feed_density is too_low
        and spiral_B feed_density is trending_downward
        and spiral_B feed_sump_level_setpoint <=
             minimum spiral_circuit_feed_sump_level_setpoint
        and  recirculating_sump level_setpoint <=
             minimum recirculating_sump_level_setpoint
        and mill feedwater_valve_position >
            minimum mill_feedwater_valve_position

        then spiral_circuit metallurgical_problem is density_too_low     cf = 100
        then mill feedwater_valve_position is decreased_a_lot             cf = 10

        then CHANGE mill feedwater_valve_position decreased_a_lot  ;      cf = 10

    then WAIT ALLCONCL spiral_circuit metallurgical_problem density_too_low 900


RULE 19
        if spiral_A feed_density is too_low
        and spiral_A feed_density is trending_downward
        and spiral_A feed_sump_level_setpoint <=
             minimum spiral_circuit_feed_sump_level_setpoint
        and  recirculating_sump level_setpoint <=
             minimum recirculating_sump_level_setpoint
        and  mill feedwater_valve_position <=
             minimum mill_feedwater_valve_position
        and  mill feed_rate_setpoint <
             maximum mill_feed_rate_setpoint

        and  mill power_draw is_not too_low
        and  mill power_draw is_not too_high

        or spiral_B feed_density is too_low
        and spiral_B feed_density is trending_downward
        and spiral_B feed_sump_level_setpoint <=
             minimum spiral_circuit_feed_sump_level_setpoint
        and  recirculating_sump level_setpoint <=
             minimum recirculating_sump_level_setpoint
        and  mill feedwater_valve_position <=
             minimum mill_feedwater_valve_position
        and  mill feed_rate_setpoint <
             maximum mill_feed_rate_setpoint

        and  mill power_draw is_not too_low
        and  mill power_draw is_not too_high

        then spiral_circuit metallurgical_problem is density_too_low     cf = 10
        then mill feed_rate_setpoint is increased_a_little_bit            cf = 10

        then CHANGE mill feed_rate_setpoint increased_a_little_bit ;      cf = 10

        then TEXT
             The spiral circuit feed density is too low.
```

```
!* silica assays too high *!

RULE 23
      if   circuit  silica_content is too_high
      and  high_tension product_grade is_not on_spec
      and  spiral_A feed_density might_be ok
      and  spiral_B feed_density might_be ok
      and  spiral_circuit cleaner_wash_water_flowrate <
           maximum spiral_cleaner_wash_water
      then spiral_circuit metallurgical_problem is silica_too_high     cf = 100
      then spiral_circuit cleaner_wash_water_setpoint is increased_a_lot  cf =

      then CHANGE spiral_circuit cleaner_wash_water_setpoint increased_a_lot ; c

      then WAIT ALLCONCL spiral_circuit metallurgical_problem silica_too_high


RULE 24
      if   circuit silica_content is too_high
      and  high_tension product_grade is_not on_spec
      and  spiral_A feed_density might_be ok
      and  spiral_B feed_density might_be ok
      and  spiral_circuit cleaner_wash_water_flowrate >=
           maximum spiral_cleaner_wash_water
      and  spiral_circuit rougher_wash_water_flowrate <
           maximum spiral_rougher_wash_water
      then spiral_circuit metallurgical_problem is silica_too_high     cf = 100
      then spiral_circuit rougher_wash_water_setpoint is increased_a_lot  cf =

      then CHANGE spiral_circuit rougher_wash_water_setpoint increased_a_lot ;c

      then WAIT ALLCONCL spiral_circuit metallurgical_problem silica_too_high


RULE 25
      if   circuit silica_content is too_high
      and  high_tension product_grade is_not on_spec
      and  spiral_A feed_density might_be ok
      and  spiral_B feed_density might_be ok
      and  spiral_circuit cleaner_wash_water_flowrate >=
           maximum spiral_cleaner_wash_water
      and  spiral_circuit cleaner_wash_water_setpoint >=
           maximum spiral_cleaner_wash_water_setpoint
      and  spiral_circuit rougher_wash_water_flowrate >=
           maximum spiral_rougher_wash_water
      and  spiral_circuit rougher_wash_water_setpoint >=
           maximum spiral_rougher_wash_water_setpoint
      then spiral_circuit metallurgical_problem is silica_too_high     cf = 10
      then TEXT
      ***************************************************
           The silica content is too high.
           Check the splitters position.
           Consider increasing the dilution water.
           If necessary close the splitters on the cleaners
           then roughers.
           If this does not help, inform the mine.
      ***************************************************     cf = 100
      then WAIT ALLCONCL spiral_circuit metallurgical_problem silica_too_high

!* here we can add rules for manipulation of dilution water - high silica *!
!* note: dilution water adjustment is not automated *!
```

```
RULE 26
      if   circuit weight_recovery is too_low
      and  circuit silica_content is_not too_high
      and  spiral_circuit cleaner_wash_water_flowrate >
           minimum spiral_cleaner_wash_water
      then spiral_circuit metallurgical_problem is weight_recovery_too_low
      then spiral_circuit cleaner_wash_water_setpoint is decreased_a_lot     cf

      then CHANGE spiral_circuit cleaner_wash_water_setpoint decreased_a_lot ;

 then WAIT ALLCONCL spiral_circuit metallurgical_problem weight_recovery_too_l

:*   In Rules 27 and 28   silica_too_low is used in the WAIT statement     *:
:*   in order to make these rules independent of rules that increase       *:
:*   the setpoint if the weight recovery is too low                        *:


RULE 27
      if   circuit weight_recovery is too_low
      and  circuit silica_content is_not too_high
      and  spiral_circuit cleaner_wash_water_flowrate <=
           minimum spiral_cleaner_wash_water
      and  spiral_circuit rougher_wash_water_flowrate >
           minimum spiral_rougher_wash_water
      then spiral_circuit metallurgical_problem is silica_too_low cf = 100
      then spiral_circuit rougher_wash_water_setpoint is decreased_a_lot   cf

      then CHANGE spiral_circuit rougher_wash_water_setpoint decreased_a_lot ;

      then WAIT ALLCONCL spiral_circuit metallurgical_problem silica_too_low

RULE 28
      if   circuit weight_recovery is too_low
      and  circuit silica_content is_not too_high
      and  spiral_circuit cleaner_wash_water_flowrate <=
           minimum spiral_cleaner_wash_water
      and  spiral_circuit rougher_wash_water_flowrate <=
           minimum spiral_rougher_wash_water
      then spiral_circuit metallurgical_problem is silica_too_low  cf = 100
      then TEXT
      ***************************************************
           The weight recovery is low, and it cannot be
           corrected by adjusting the spiral wash waters.
           This may be caused by the blend of ore.
           Inform the mine.
      ***************************************************$      cf = 100
      then WAIT ALLCONCL spiral_circuit metallurgical_problem silica_too_low ;


:* weight recovery too high *:
```

```
RULE 29
        if   circuit weight_recovery is too_high
        and  mill feed_rate_setpoint >
             minimum mill_feed_rate_setpoint
        then spiral_circuit metallurgical_problem is weight_recovery_too_high c
        then mill feed_rate_setpoint is decreased_a_little_bit                  cf =

        then CHANGE mill feed_rate_setpoint decreased_a_little_bit ;        cf =

        then TEXT
        ==========================================================
             The mill feed rate was decreased because the
             weight recovery is too high.

             You should inform the mine about this.
        ==========================================================#       cf = 100
        then WAIT 4200 ;                                                  cf = 100

!*************************  SPIRAL OPERATING CONDITIONS   ** ****************

RULE 30
        if spiral_A sump_level is too_high
        and spiral_A feed_flowrate is_not ok
        then spiral_A spiral_operating_problem is sump_overload  cf = 100
        then TEXT
        ==========================================================
             Spiral A feed pump seems to be malfunctioning.
             Check this and call maintenance if necessary.
        ==========================================================#       cf = 100
        then WAIT ALLCONCL spiral_A spiral_operating_problem sump_overload 600 ;

RULE 31

        if spiral_B sump_level is too_high
        and spiral_B feed_flowrate is_not ok
        then spiral_B spiral_operating_problem is sump_overload  cf = 100
        then TEXT
        ==========================================================
             Spiral B feed pump seems to be malfunctioning.
             Check this and call maintenance if necessary.
        ==========================================================#       cf = 100
        then WAIT ALLCONCL spiral_B spiral_operating_problem sump_overload 600 ;

RULE 32
        if spiral_A sump_level is too_high
        and spiral_A sump_level is trending_upward
        and spiral_A feed_flowrate is ok
        then spiral_A spiral_operating_problem is sump_overload  cf = 100
        then TEXT
        ==========================================================
             Spiral A sump level is too high and is trending
             upward. Check the feed pump.
        ==========================================================#       cf = 100
        then WAIT ALLCONCL spiral_A spiral_operating_problem sump_overload 600 ;
```

```
RULE 33
        if spiral_B sump_level is too_high
        and spiral_B sump_level is trending_upward
        and spiral_B feed_flowrate is ok
        then spiral_B spiral_operating_problem is sump_overload  cf = 100
        then TEXT
        ==========================================================
             Spiral B sump level is too high and is trending
             upward. Check the feed pump.
        ==========================================================#      cf = 100
        then WAIT ALLCONCL spiral_B spiral_operating_problem sump_overload 600 ;

RULE 34
        if spiral_A sump_level is too_low
        and spiral_A sump_level is_not trending_upward
        then spiral_A spiral_operating_problem is screen_blocked  cf = 100
        then TEXT
        ==========================================================
             Spiral A sump level is too low and is trending
             downward. Check your sizing screens.
        ==========================================================#      cf = 100
        then WAIT ALLCONCL spiral_A spiral_operating_problem screen_blocked 600

RULE 35
        if spiral_B sump_level is too_low
        and spiral_B sump_level is_not trending_upward
        then spiral_B spiral_operating_problem is screen_blocked  cf = 100
        then TEXT
        ==========================================================
             Spiral B sump level is too low and is trending
             downward. Check your sizing screens.
        ==========================================================#      cf = 100
        then WAIT ALLCONCL spiral_B spiral_operating_problem screen_blocked 600


!********  RULES TO CORRECT MILL OPERATION PROBLEMS  ***********!

!*********  overload  ************!

RULE 36
        if mill power_draw is too_high
        and mill power_draw is trending_upward_fast
        then mill operating_problem is critical_overload          cf = 100
        then mill feed_rate_setpoint is decreased_a_lot           cf = 100

        then CHANGE mill feed_rate_setpoint decreased_a_lot  ;    cf = 100

        then TEXT
        ==========================================================
          The power draw on the mill is too high and is trending up.

          The feed rate has just been decreased.
        ==========================================================# cf = 100
        then WAIT 300 ;                                             cf = 100
        then WAIT ALLCONCL mill operating_problem overload 300 ;    cf = 100
        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1200 ;
        then WAIT ALLCONCL mill feed_rate_setpoint increased_a_lot 1200 ;   cf
        then WAIT ALLCONCL mill feed_rate_setpoint increased_a_little_bit 1200 ;
```

RULE 37
if mill power_draw is critically_high
then mill operating_problem is critical_overload cf = 100
then mill feed_rate_setpoint is decreased_immediately cf = 10

then CHANGE mill feed_rate_setpoint decreased_immediately ; cf = 10

then TEXT
"""
The power draw on the mill is CRITICALLY HIGH.

The feed rate has just been decreased.
""" cf = 100
cf = 100
then WAIT 120 ; cf = 100
then WAIT ALLCONCL mill operating_problem overload 120 ;
then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1200 ;
then WAIT ALLCONCL mill feed_rate_setpoint increased_a_lot 1200 ; cf
then WAIT ALLCONCL mill feed_rate_setpoint increased_a_little_bit 1200

RULE 38
if mill power_draw is high_power_ore
and mill power_draw is trending_upward_fast
and recirculating_load density is_not too_high
and recirculating_load density is_not trending_upward
and recirculating_sump level is too_high
and recirculating_sump level is trending_upward
and mill feedwater_valve_position >
minimum mill_feedwater_valve_position

or ore type is high_power_ore
and recirculating_load density is_not too_high
and recirculating_load density is_not trending_upward
and recirculating_sump level is too_high
and recirculating_sump level is trending_upward
and mill feedwater_valve_position >
minimum mill_feedwater_valve_position

cf = 100
then mill operating_problem is overload
then mill feedwater_valve_position is decreased_a_little_bit cf = 100

then CHANGE mill feedwater_valve_position decreased_a_little_bit ; cf =

then TEXT
"""
The recirculating sump level is too high and it
is trending upward. The mill feedwater has been
decreased by a small amount.

NOTE: The ore type is high power ore.
""" cf = 100
then WAIT ALLCONCL mill operating_problem overload 120 ; cf = 100

```
RULE 39
        if mill power_draw is high_power_ore
        2nd mill power_draw is trending_upward_fast
        and recirculating_load density is too_high
        and recirculating_load density is trending_upward
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward

        or ore type is high_power_ore
        and recirculating_load density is too_high
        and recirculating_load density is trending_upward
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward

        then mill operating_problem is overload                    cf = 100
        then mill feed_rate_setpoint is decreased_a_lot            cf = 100

        then CHANGE mill feed_rate_setpoint decreased_a_lot ;      cf = 100

        then TEXT
        ==========================================================
          The power draw on the mill is high and trending up.
          The recirculating load density and sump level are
          too high.

             The mill feed rate has just been decreased.
        ==========================================================  cf = 100
        then WAIT ALLCONCL mill operating_problem overload 600 ;    cf = 100


RULE 40
        if mill power_draw is high_power_ore
        and mill power_draw is trending_upward_fast
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward
        and mill feedwater_valve_position <=
            minimum mill_feedwater_valve_position

        or ore type is high_power_ore
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward
        and mill feedwater_valve_position <=
            minimum mill_feedwater_valve_position

        then mill operating_problem is overload                    cf = 100

        then TEXT
        ==========================================================
             The recirculating sump level is too high and it
             is trending upward. The mill feedwater is at its
             minimum value. Monitor the recirculating sump
             for possible overflow.

             NOTE: The ore type is high power ore.
        ==========================================================  cf = 100
        then WAIT 600 ;                                             cf = 100
```

```
RULE 41
      if mill power_draw is low_power_ore
      and mill power_draw is trending_downward_fast
      and recirculating_load density is_not too_high
      and recirculating_load density is_not trending_upward
      and  recirculating_sump level is too_high
      and  recirculating_sump level is trending_upward
      and mill feedwater_valve_position >
          minimum mill_feedwater_valve_position

      or ore type is low_power_ore
      and recirculating_load density is_not too_high
      and recirculating_load density is_not trending_upward
      and  recirculating_sump level is too_high
      and  recirculating_sump level is trending_upward
      and mill feedwater_valve_position >
          minimum mill_feedwater_valve_position

      then mill operating_problem is overload                          cf = 100
      then mill feedwater_valve_position is decreased_a_little_bit cf = 100

      then CHANGE mill feedwater_valve_position decreased_a_little_bit ; cf =

      then TEXT
      ==========================================================
           The power draw on the mill is too low and the
           recirc sumpl level is too high.
           Check for plugged pumps and grates.

           The mill water addition has just been decreased.
      ==========================================================#    cf = 100
      then WAIT ALLCONCL mill operating_problem overload 300 ;       cf = 100


RCLE 42
      if mill power_draw is low_power_ore
      and mill power_draw is trending_downward_fast
      and recirculating_load density is too_high
      and recirculating_load density is trending_upward
      and  recirculating_sump level is too_high
      and  recirculating_sump level is trending_upward

      or ore type is low_power_ore
      and recirculating_load density is too_high
      and recirculating_load density is trending_upward
      and  recirculating_sump level is too_high
      and  recirculating_sump level is trending_upward

      then mill operating_problem is overload                          cf = 100
      then mill feed_rate_setpoint is decreased_a_lot                  cf = 100

      then CHANGE mill feed_rate_setpoint decreased_a_lot ;            cf = 100

      then TEXT
      ==========================================================
           The power draw on the mill is getting too low
           and the recirculating load density is too high.

           The feed rate has just been decreased.
      ==========================================================#    cf = 100
      then WAIT ALLCONCL mill operating_problem overload 300 ;       cf = 100
```

```
RULE 43
        if mill power_draw is low_power_ore
        and mill power_draw is trending_downward_fast
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward
        and mill feedwater_valve_position <=
            minimum mill_feedwater_valve_position

        or ore type is low_power_ore
        and  recirculating_sump level is too_high
        and  recirculating_sump level is trending_upward
        and mill feedwater_valve_position <=
            minimum mill_feedwater_valve_position

        then mill operating_problem is overload                    cf = 100

        then TEXT
        ************************************************************
             The power draw on the mill is too low and the
             recirculating sump level is too high.
             The feedwater is at its minimum value.

             Monitor the situation for possible overflow of
             the recirculating sump.

             Check for plugged pumps and grates.
        ************************************************************#   cf = 100
        then WAIT 600 ;   cf = 100 #


RULE 44
        if mill power_draw is too_low
        then mill operating_problem is low_power                   cf = 100
        then TEXT
        ************************************************************
             The power draw on the mill is too low.
             Are you grinding-out ?

             If you aren't, check for mill backspilling or
             frozen feeder.
        ************************************************************#   cf = 100 -
        then WAIT ALLCONCL mill operating_problem overload 300 ;   cf = 100 #

!********* Recirc pump box too high or overflowing ***********!


RULE 45
        if  recirculating_sump level is too_high
        and recirculating_load flowrate is too_low
        then mill operating_problem is overload                    cf = 100
        then TEXT
        ************************************************************
             The recirc sump level is too high
             and the recirc load flowrate is too low
             Check that the pump is working well and
             call maintenance if necessary.
        ************************************************************#   cf = 100
        then WAIT ALLCONCL mill operating_problem overload 600 ;   cf = 100
```

```
RULE 46
      if  recirculating_sump level is too_high
      and recirculating_sump level is trending_upward_fast
      then mill operating_problem is overload                          cf = 100
      then TEXT
      ***************************************************************
        The recirc sump level is too high and is trending
        upward fast.

           Check that the screens are plugged or the
           recirculating load from the spiral plant is
           too high.
      ***************************************************************#    cf = 100
      then WAIT 600 ;                                                  cf = 100 #


!********* Recirc flowrate too low ************!


RULE 47
      if  recirculating_load flowrate is too_low
      and recirculating_load flowrate is trending_downward_fast
      then mill operating_problem is pump_problem                      cf = 100
      then TEXT
      ***************************************************************
           Check that the recirc pump is working well and
           call maintenance if necessary. The flowrate is
           too low and is trending downward fast.
      ***************************************************************#    cf = 100
      then WAIT ALLCONCL mill operating_problem pump_problem 600 ;      cf =


!********* Feed conveyor trip out  ************!


RULE 48
      if mill feedrate is too_low
      then mill operating_problem is no_feed                           cf = 100
      then TEXT
      ***************************************************************
           The feed rate is too low. Are you grinding out ?
           If not, the mill conveyor has tripped out.
           Check if the feed chute is plugged or that
           someone has pulled a safety cord, or a mechanical
      ------problem associated with the feeders. ----------
      ***************************************************************#    cf = 100
      then WAIT ALLCONCL mill operating_problem no_feed 60 ;           cf = 100 #
```

```
!*********  Mill backspilling  ************;

RULE 49
      if mill condition is backspilling
      then mill operating_problem is backspilling                    cf = 100
      then mill feed_rate_setpoint is decreased_a_lot                cf = 100

      then CHANGE mill feed_rate_setpoint decreased_a_lot ;          cf = 100

      then TEXT
      ==========================================================
           The mill is backspilling. This may be due to
           the grates on the mill being plugged or too
           much material in the mill.

           The feed rate has just been decreased.
      ==========================================================#    cf = 100
      then DATAMAN PUT mill condition backspilling  0 ;              cf = 100 #

!*********  Recirc pump box too low  ************;

RULE 50
      if  recirculating_sump level is too_low
      and recirculating_sump level is trending_downward
      then mill operating_problem is recirc_sump_valve_problem  cf = 100
      then TEXT
      ==========================================================
       The recirc sump level is too low and is trending down.
           Check that the sump make up water valve
           is not stuck.
      ==========================================================#    cf = 100
      then WAIT ALLCONCL mill operating_problem recirc_sump_valve_problem 300

!* In the rule below care is taken to ensure that the feedwater valve **!
!* does not go below a minimum value that is determined and set by    **!
!* the operator. ***************************************************;

RULE 51
      if mill feed_water_valve_position <
         minimum mill_feedwater_valve_position

      then mill operating_problem is feed_water_valve_problem    cf = 100

       then ASNVALUE mill feed_water_valve_position
            TRIP minimum mill_feedwater_valve_position # ; cf = 100 #


!*********  DENSITY CONTROL IN MILL  ************;

!* note that we will sacrifice mill density in favor of spiral feed density
   this is evidenced by us not taking control action for correcting mill
   density when this will exacerbate the state of the spiral feed density *.
```

```
RULE 52
        if recirculating_load density is too_high
        and recirculating_load density is trending_upward_fast
        then mill operating_problem is density_too_high                cf = 100
        then mill feed_rate_setpoint is decreased_a_lot                cf = 100

        then CHANGE mill feed_rate_setpoint decreased_a_lot ;          cf = 100
        then TEXT
        ************************************************************
          The recirculating load density is too high and is
          trending upward fast.
          The feedrate has been decreased to avoid plugging
          the pump.
          Check that the screens are not blocked.
        ************************************************************#    cf = 100
        then WAIT ALLCONCL mill operating_problem density_too_high 300 ; cf = 10


RULE 53
        if recirculating_load density is too_high
        and recirculating_load density is trending_upward
        and spiral_A feed_density is_not too_low
        and spiral_A feed_density is_not trending_downward_fast
        and spiral_B feed_density is_not too_low
        and spiral_B feed_density is_not trending_downward_fast
        and recirculating_sump level_setpoint <
            maximum recirculating_sump_level_setpoint
        then mill operating_problem is density_too_high                cf = 10
        then recirculating_sump level_setpoint is increased_a_lot      cf = 10

        then CHANGE recirculating_sump level_setpoint increased_a_lot ;  cf = 10

        then WAIT ALLCONCL mill operating_problem density_too_high 300 ; cf = 10


RULE 54
        if recirculating_load density is too_high
        and recirculating_load density is trending_upward
        and spiral_A feed_density is_not too_low
        and spiral_A feed_density is_not trending_downward_fast
        and spiral_B feed_density is_not too_low
        and spiral_B feed_density is_not trending_downward_fast
        and recirculating_sump level_setpoint >=
            maximum recirculating_sump_level_setpoint
        and mill feedwater_valve_position <
            maximum mill_feedwater_valve_position
        then mill operating_problem is density_too_high                cf = 10
        then mill feedwater_valve_position is increased_a_little_bit   cf = 1

        then CHANGE mill feedwater_valve_position increased_a_little_bit ; cf =

        then WAIT ALLCONCL mill operating_problem density_too_high 600 ; cf = 10


/* Here we cut back on mill feedrate as a last resort to help with high
   mill density */
```

```
RULE 55
      if recirculating_load density is too_high
      and recirculating_load density is trending_upward
      and spiral_A feed_density is_not too_low
      and spiral_A feed_density is_not trending_downward_fast
      and spiral_B feed_density is_not too_low
      and spiral_B feed_density is_not trending_downward_fast
      and recirculating_sump level_setpoint >=
          maximum recirculating_sump_level_setpoint
      and mill feedwater_valve_position >=
          maximum mill_feedwater_valve_position
      then mill operating_problem is density_too_high                    cf = 10
      then mill feed_rate_setpoint is decreased_a_little_bit             cf = 10

      then CHANGE mill feed_rate_setpoint decreased_a_little_bit ;       cf = 10

      then TEXT
      ************************************************
           The recirculating load density is too high
           and the feedwater is at its maximum.

           The feed rate has just been decreased.
      ************************************************#    cf = 100
      then WAIT ALLCONCL mill operating_problem density_too_high 600 ; cf = 10


!* mill density is too low *!


RULE 56
      if recirculating_load density is too_low
      and recirculating_load density is trending_downward
      and spiral_A feed_density is_not too_high
      and spiral_A feed_density is_not trending_upward_fast
      and spiral_B feed_density is_not too_high
      and spiral_B feed_density is_not trending_upward_fast
      and recirculating_sump level_setpoint >
          minimum recirculating_sump_level_setpoint
      then mill operating_problem is density_too_low                     cf = 100
      then recirculating_sump level_setpoint is decreased_a_lot          cf = 100

      then CHANGE recirculating_sump level_setpoint decreased_a_lot ; cf = 100

      then WAIT ALLCONCL mill operating_problem density_too_low 300 ; cf = 100


RULE 57
      if recirculating_load density is too_low
      and recirculating_load density is trending_downward
      and spiral_A feed_density is_not too_high
      and spiral_A feed_density is_not trending_upward_fast
      and spiral_B feed_density is_not too_high
      and spiral_B feed_density is_not trending_upward_fast
      and recirculating_sump level_setpoint <=
          minimum recirculating_sump_level_setpoint
      and mill feedwater_valve_position >
          minimum mill_feedwater_valve_position
      then mill operating_problem is density_too_low                     cf = 10
      then mill feedwater_valve_position is decreased_a_little_bit       cf = 10

      then CHANGE mill feedwater_valve_position decreased_a_little_bit ; cf =

      then WAIT ALLCONCL mill operating_problem density_too_low 600 ; cf = 100
```

```
RCLE 58
      if recirculating_load density is too_low
      and recirculating_load density is trending_downward
      and spiral_A feed_density is_not too_high
      and spiral_A feed_density is_not trending_upward_fast
      and spiral_B feed_density is_not too_high
      and spiral_B feed_density is_not trending_upward_fast
      and recirculating_sump level_setpoint <=
          minimum recirculating_sump_level_setpoint
      and mill feedwater_valve_position <=
          minimum mill_feedwater_valve_position
      and  mill feed_rate_setpoint <
           maximum mill_feed_rate_setpoint
      and mill power_draw is_not too_high
      and mill power_draw is_not too_low
      then mill operating_problem is density_too_low                    cf = 100
      then mill feed_rate_setpoint is increased_a_little_bit            cf = 100

      then CHANGE mill feed_rate_setpoint increased_a_little_bit ;      cf = 100

      then TEXT
      ***************************************************
        Your mill feedrate was just increased because the
        recirculating load density is too low and the
        feedwater is at its minimum.
      ***************************************************     cf = 100
      then WAIT ALLCONCL mill operating_problem density_too_low 600 ; cf = 100


!* to increase the mill feed *!


RCLE 59
      if  circuit weight_recovery is too_low
      and mill feed_rate_setpoint <
          maximum mill_feed_rate_setpoint
      and spiral_A feed_density is_not too_high
      and spiral_A feed_density is_not trending_upward_fast
      and spiral_B feed_density is_not too_high
      and spiral_B feed_density is_not trending_upward_fast
      and recirculating_sump level_setpoint <
          maximum recirculating_sump_level_setpoint
      and mill feedwater_valve_position <
          maximum mill_feedwater_valve_position
      and mill power_draw is_not too_high
      and mill power_draw is_not too_low
      then mill operating_problem is weight_recovery_too_low        cf = 100
      then mill feed_rate_setpoint is increased_a_lot               cf = 100

      then CHANGE mill feed_rate_setpoint increased_a_lot          ; cf = 100

      then TEXT
      ***************************************************
            The mill feedrate was increased because
             the weight recovery is low.
      ***************************************************     cf = 100
      then WAIT ALLCONCL mill operating_problem weight_recovery_too_low 4200



!** then mill feedwater_valve_position is increased_a_lot          cf = 100 ***
!** then CHANGE mill feedwater_valve_position increased_a_lot    ; cf = 100 ***
```

```
RULE 60
      if  circuit weight_recovery is too_low
      and mill feed_rate_setpoint <
          maximum mill_feed_rate_setpoint
      and recirculating_sump level_setpoint <
          maximum recirculating_sump_level_setpoint
      and mill feedwater_valve_position <
          maximum mill_feedwater_valve_position
      and mill power_draw is_not too_high
      and mill power_draw is_not too_low
      then mill operating_problem is weight_recovery_too_low       cf = 100
      then mill feed_rate_setpoint is increased_a_lot              cf = 100

      then CHANGE mill feed_rate_setpoint increased_a_lot        ; cf = 100

      then TEXT
      ***************************************************
              The mill feedrate was just increased
              because the weight recovery is low.
      ***************************************************;    cf = 100
      then WAIT ALLCONCL mill operating_problem weight_recovery_too_low 4200 ;


!** then mill feedwater_valve_position is increased_a_lot    cf = 100     ***:
!** then CHANGE mill feedwater_valve_position increased_a_lot ; cf = 100  ***:


RULE 61
      if  circuit weight_recovery is_not too_high
      and mill power_draw is_not too_high
      and recirculating_load density is_not too_high
      and recirculating_load density is_not trending_upward_fast
      and mill feed_rate_setpoint <
          maximum mill_feed_rate_setpoint
      then mill operating_problem is low_feed_rate_setpoint        cf = 100
      then mill feed_rate_setpoint is increased_a_lot              cf = 100

      then CHANGE mill feed_rate_setpoint increased_a_lot        ; cf = 100

      then TEXT
      ***************************************************
            The mill feedrate  was just increased.
            This is an aggressive action to increase tonnage.
            Monitor the situation carefully.
      ***************************************************;    cf = 100
      then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 4200 ;


!*** then mill feedwater_valve_position is increased_a_lot   cf = 100   ***:
!*** then CHANGE mill feedwater_valve_position increased_a_lot ;cf = 100 **:
```

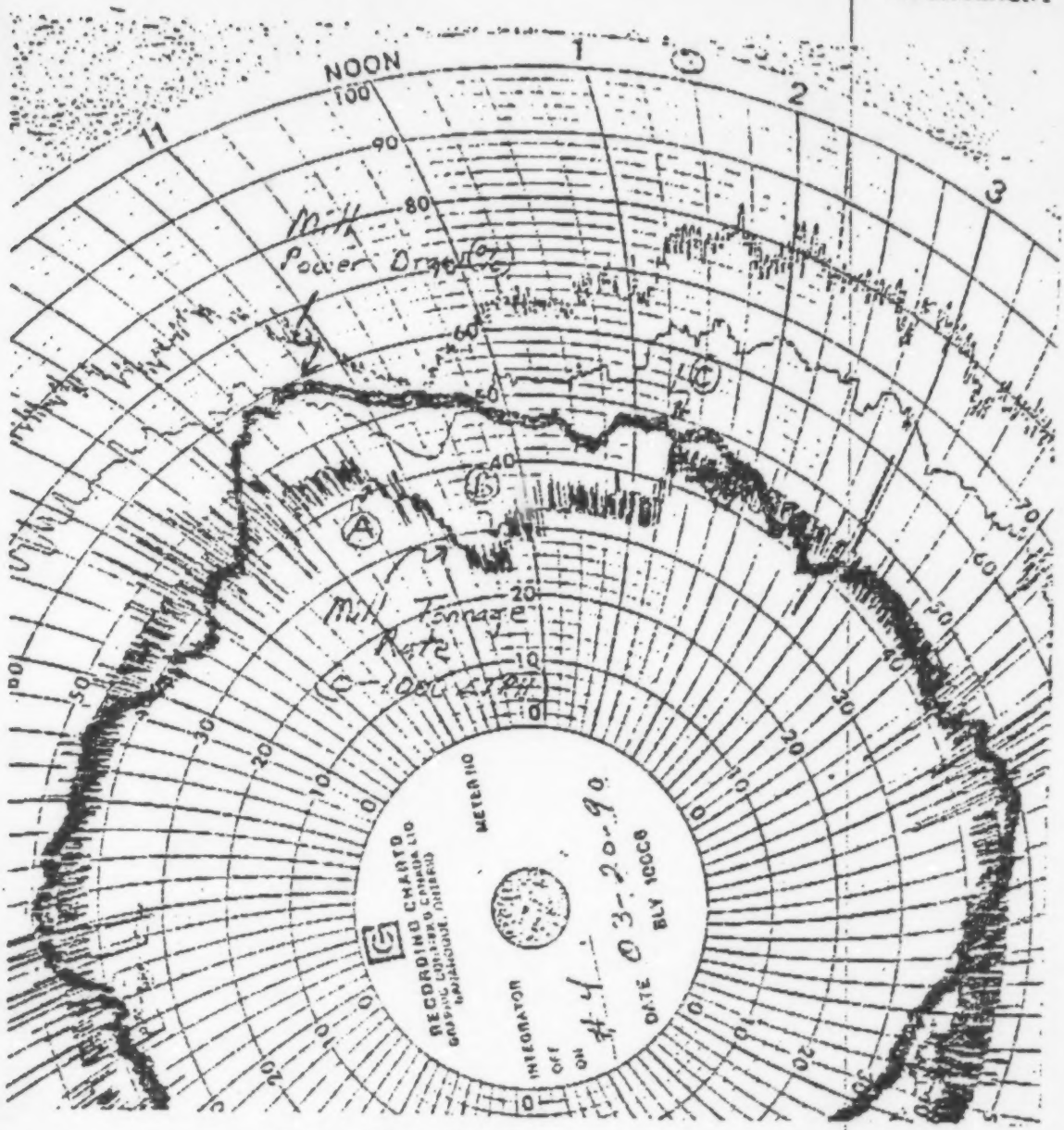
```
RULE 62
        if ore type is normal_power_ore
        and recirculating_load density is_not too_high
        and recirculating_load density is_not trending_upward_fast
        and spiral_A feed_density is_not too_high
        and spiral_A feed_density is_not trending_upward_fast
        and spiral_B feed_density is_not too_high
        and spiral_B feed_density is_not trending_upward_fast
        and recirculating_sump level is_not too_high
        and recirculating_sump level is_not trending_upward_fast
        and spiral_A sump_level is_not too_high
        and spiral_A sump_level is_not trending_upward_fast
        and spiral_B sump_level is_not too_high
        and spiral_B sump_level is_not trending_upward_fast
        and circuit weight_recovery is_not too_high
        and mill feed_rate_setpoint is low
        then mill operating_problem is low_feed_rate_setpoint       cf = 100

        then mill feed_rate_setpoint is increased_to_normal_level    cf = 100

        then CHANGE mill feed_rate_setpoint increased_to_normal_level ;  cf = 10
        then TEXT
        ***************************************************
             The mill feedrate was just increased
             because we have normal ore and the feedrate
             setpoint is low.
        ***************************************************#    cf = 100
        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 4200 ;


!*  then mill feedwater_valve_position is increased_a_lot       cf = 100    *!
!*  then CHANGE mill feedwater_valve_position increased_a_lot ; cf = 100    *!


!***  The following rules will try to re-established the normal mill  ***!
!***  feedrate after a decrease caused by mill operating problems     **!


RULE 63
        if mill operating_problem is critical_overload
        and mill power_draw is_not too_high
        and mill power_draw is_not trending_upward_fast
        and mill feed_rate_setpoint is low
        then mill operating_problem is low_feed_rate_setpoint       cf = 100

        then mill feed_rate_setpoint is increased_to_normal_level    cf = 100

        then CHANGE mill feed_rate_setpoint increased_to_normal_level ;  cf = 10
        then TEXT
        ***************************************************
             The mill feedrate was just increased.
           This action was taken because the feedrate was
           decreased due to high power draw but the power
           draw has since decreased.
        ***************************************************#    cf = 100

        then DATAMAN PUT mill operating_problem critical_overload  0 ;  cf = 10

        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1800 ;
```

```
RULE 64
        if mill operating_problem is density_too_high
        and recirculating_load density is_not too_high
        and recirculating_load density is_not trending_upward_fast
        and mill power_draw is_not too_high
        and mill power_draw is_not trending_upward_fast
        and mill feed_rate_setpoint is low
        then mill operating_problem is low_feed_rate_setpoint        cf = 100

        then mill feed_rate_setpoint is increased_to_normal_level    cf = 100

        then CHANGE mill feed_rate_setpoint increased_to_normal_level ;  cf = 10
        then TEXT
        ************************************************************
             The mill feedrate was just increased.
           This action was taken because the feedrate was
           decreased due to high recirculating load density
           but the density has since decreased.
        ************************************************************#    cf = 100

        then DATAMAN PUT mill operating_problem density_too_high  0 ;  cf = 100

        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1800 ;


RULE 65
        if spiral_circuit metallurgical_problem is density_too_high
        and spiral_A feed_density is_not too_high
        and spiral_A feed_density is_not trending_upward
        and spiral_B feed_density is_not too_high
        and spiral_B feed_density is_not trending_upward
        and mill power_draw is_not too_high
        and mill power_draw is_not trending_upward_fast
        and mill feed_rate_setpoint is low
        then mill operating_problem is low_feed_rate_setpoint        cf = 100

        then mill feed_rate_setpoint is increased_to_normal_level    cf = 100

        then CHANGE mill feed_rate_setpoint increased_to_normal_level ;  cf = 100
        then TEXT
        ************************************************************
             The mill feedrate was just increased.
           This action was taken because the feedrate was
           decreased due to high spiral feed density
           but the density has since decreased.
        ************************************************************#    cf = 100

      then DATAMAN PUT spiral_circuit metallurgical_problem density_too_high 0 ; cf

        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1800 ; cf
```

```
RULE 66
        if mill operating_problem is overload
        and recirculating_load density is_not too_high
        and recirculating_load density is_not trending_upward
        and  recirculating_sump level is_not too_high
        and  recirculating_sump level is_not trending_upward
        and mill power_draw is_not too_high
        and mill power_draw is_not trending_upward_fast
        and mill feed_rate_setpoint is low
        then mill operating_problem is low_feed_rate_setpoint       cf = 100

        then mill feed_rate_setpoint is increased_to_normal_level    cf = 100

        then CHANGE mill feed_rate_setpoint increased_to_normal_level ;  cf = 10
        then TEXT
        ***************************************************
             The mill feedrate was just increased.
          This action was taken because the feedrate was
          decreased due to high recirculating load density
          and recirculating sump level but these have
          since decreased.
        ***************************************************#    cf = 100

        then DATAMAN PUT mill operating_problem overload  0 ;  cf = 100

        then WAIT ALLCONCL mill operating_problem low_feed_rate_setpoint 1800 ;
```

```
!* default value of variables *!

DEFAULT
      ore type normal_power_ore                    100
      ore type known                               100
      mill power_draw normal_power_ore             100
      spirals metallurgical_performance ok         100
      spirals operating_condition ok               100
      mill operating_condition ok                  100
      mill operating_problem overload              0
      mill operating_problem critical_overload     0
      mill operating_problem density_too_high      0
      spiral_circuit metallurgical_problem density_too_high 0


      maximum spiral_rougher_wash_water # 2  100

      maximum spiral_rougher_wash_water_setpoint # 2  100

      maximum spiral_cleaner_wash_water # 14  100

      maximum spiral_cleaner_wash_water_setpoint # 14  100

      maximum recirculating_sump_level_setpoint # 75  100

      maximum spiral_circuit_feed_sump_level_setpoint #  75  100
```

```
maximum mill_feedwater_valve_position # 60 100
minimum mill_feedwater_valve_position # 10 100
minimum spiral_circuit_feed_sump_level_setpoint # 25 100

minimum spiral_rougher_wash_water # 0.5 100
minimum spiral_rougher_wash_water_setpoint # 0.5 100
minimum spiral_cleaner_wash_water # 8 100
minimum spiral_cleaner_wash_water_setpoint # 8 100
minimum recirculating_sump_level_setpoint # 25 100


mill power_draw trending_upward_fast 0
mill power_draw trending_downward_fast 0
mill power_draw steady_low_power 0
mill power_draw steady_normal_power 100
mill power_draw steady_high_power 0
recirculating_load flowrate trending_downward_fast 0
recirculating_load density trending_upward 0
recirculating_load density trending_downward 0
recirculating_load density trending_upward_fast 0
recirculating_sump level trending_upward 0
recirculating_sump level trending_downward 0
recirculating_sump level trending_upward_fast 0

spiral_A feed_density trending_downward_fast 0
spiral_B feed_density trending_downward_fast 0

spiral_A feed_density trending_upward_fast 0
spiral_B feed_density trending_upward_fast 0

spiral_A feed_density trending_upward 0
spiral_B feed_density trending_upward 0

spiral_A feed_density trending_downward 0
spiral_B feed_density trending_downward 0

spiral_A sump_level trending_upward_fast 0
spiral_B sump_level trending_upward_fast 0

spiral_A sump_level trending_upward 0
spiral_B sump_level trending_upward 0
```



Recording Chart for Mill #4 While Under Expert System Control

Note: Point A Mill tonnage is decreased from 425 LTPH when power reaches critical level of 60 %

Point B Mill tonnage begins to be increased after power draw has declined.

Point C Mill tonnage has been reestablished at desired rate of 425 LTPH.